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PHYSICAL GEOGRAPHY OF NEW YORK STATE.

BY

RALPH S. TARR.

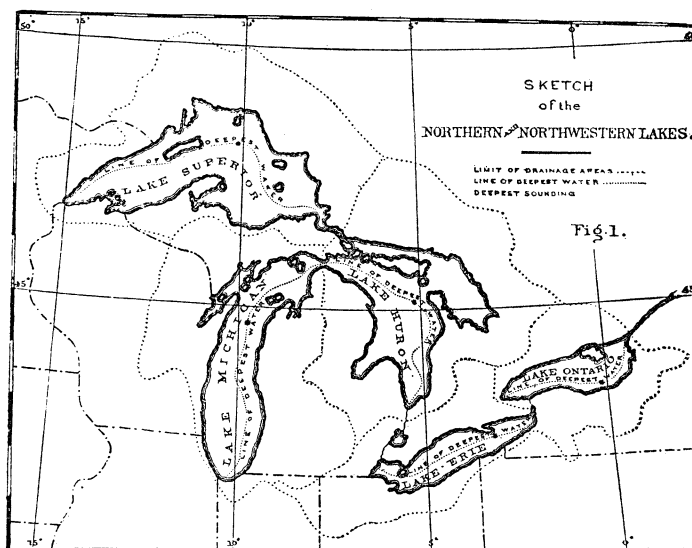
PART VII.—THE GREAT LAKES AND NIAGARA.

THE GREAT LAKES.

DESCRIPTION OF THE ST. LAWRENCE SYSTEM.*—The St. Lawrence is quite unique among the river systems of the world. At its mouth the river and its tributaries are drowned, so that the salt water of the ocean enters to form the broad Bay of St. Lawrence, with its irregular margin. Even further out than this, there is indication of a river valley carved in the continental shelf and completely covered by the ocean. From the Bay of St. Lawrence up stream the water area narrows and the water freshens, though the tide rises nearly as far as Montreal, at which place the St. Lawrence is a very broad river, with gentle current. Just above this place, the river changes in habit, becoming a series of violent rapids, and from this point up stream there are frequent stretches of quiet water, separated by rapids. Then, at the outlet of Lake Ontario, the river passes through a maze of islands, beyond which is Lake Ontario itself, one of the five Great Lakes, which, because of their immense size and close connection, constitute one of the remarkable features of the system.

* Schermerhorn, Amer. Journ. Sci., 1887, CXXXIII, 278-284; Vedel, Amer. Geol., 1896, XVIII, 196; Bigsby, Phil. Mag., 1829, 2nd Ser., V, 1-15; 81-87; 263-274; 339-347; 424-431; Henry, Trans. Albany Inst., 1830, I, 87-112.

These several lakes are connected by broad rivers and straits, which, in places navigable, are elsewhere interrupted by rapids, and in one case by the greatest fall in the world, Niagara. The water area above the Thousand Islands outlet of Lake Ontario, including the lakes and connecting streams, is about 95,275 square miles;* but to this entire area there is no large river tributary. As will be



SCHERMERHORN'S SKETCH MAP OF THE GREAT LAKES.

seen by the map (Fig. 1), the divide of the system sometimes runs close to the lakes, and is never very far from them. The total area of the Great Lake system is about 270,000 square miles, of which, as has been said, about 95,275 square miles is water. This of itself is a remarkable feature, and will be referred to later as having an important bearing on the history of the St. Lawrence system.

"The water surface of Lake Superior nearly equals the combined areas of New Hampshire, Vermont, Massachusetts and Connecticut"; and the "combined area of the lakes exceeds the area of England, Wales and Scotland"; while "the length of shore line of the lakes and their connecting rivers is about 5,400 miles, or about equal to the coast line from Maine to the isthmus of Panama," ignoring minor indentations.†

* Most of the figures and facts in this section are taken from Schermerhorn's valuable paper, *Amer. Journ. Sci.*, 1887, CXXXIII, 278-284.

† Schermerhorn, *Amer. Journ. Sci.*, 1887, CXXXIII, 279.

	LENGTH, MILES.	AVERAGE WIDTH, MILES.	MAXIMUM WIDTH, MILES.	SHORE LINE, MILES.	WATER AREA (INCLUDING ISLANDS), SQUARE MILES.	AVERAGE DEPTH, FEET.	MAXIMUM DEPTH SOUNDED, FEET.	SURFACE ABOVE TIDE-WATER, FEET.	DEEPEST POINT ABOVE TIDEWATER, FEET.	WATER VOLUME, CUBIC MILES.	LAND AREA OF WATER SHED, SQUARE MILES.	AGGREGATE WATER AND LAND AREA OF WATER SHED, SQUARE MILES.
Lake Superior.....	390	70	160	1,300	31,200	475	1,008	602	-406	2,800	51,600	82,800
St. Mary's River.....	53	2½	5	100	200	..	53	..	..	..	800	1,000
Lake Michigan.....	40	2	4	..	..	..	..	..	..	..	..	..
Green Bay.....	335	58	85	875	20,200	335	870	581	-289	1,290	..	..
Mackinac Strait.....	115	15	21	260	1,700	95	144	581	+437	30	37,700	60,100
North Channel.....	30	16	23	60	500	75	234	581	+347	7	..	..
Lake Huron.....	110	12	18	220	14,400	70	240	581	+341	20	..	..
Lake Huron.....	250	54	100	725	17,400	210	702	581	-121	650	31,700	55,700
Georgian Bay.....	120	40	58	390	5,200	170	462	581	+119	170	..	..
St. Clair River.....	35	1	..	70	30	..	..	..	..	..	3,800	3,830
Lake St. Clair.....	19	25	20	90	410	..	21	575	+554	1	3,400	3,810
Detroit River.....	27	2	3½	54	60	..	..	..	..	..	1,200	1,260
Lake Erie.....	25	40	58	590	10,000	70	204	573	+369	130	22,700	32,700
Niagara River.....	34	1	2	70	60	..	..	..	..	..	300	360
Lake Ontario.....	180	40	58	600	7,300	300	738	247	-491	410	21,600	28,900
St. Lawrence River....	760	20	95	..	..	..	..	..	..	..	..	..
Totals.....				5,404	95,660					5,508	174,800	270,460

Table copied from American Geologist (by Vedel), 1896, XVIII., p. 196.

From the table it is seen that Lake Superior is 602 feet above sea level, Huron and Michigan 581 feet, the descent between them being chiefly in the rapids of St. Mary's River. There is then a descent of about 8 feet to the level of Erie (573), mostly in Detroit River, while Ontario has an elevation of about 247 feet. Of this descent, 160 feet occurs *at* the Falls, 110 feet in the rapids of the gorge, and 50 feet in the rapids just above the Falls. This leaves only 6 feet of fall for the upper Niagara River above the rapids.

The beds of the lakes, excepting Erie, are below sea level, and so much is below this level that even if their water surface were lowered down to the level of the sea, there would still remain large bodies of water in the sites of Ontario, Michigan and Superior, while Erie would disappear and Huron shrink to small size.

The rainfall of the entire lake area averages about 31 inches, being higher in the eastern than the northwestern end. This rainfall fills the lakes, satisfies percolation and evaporation, and furnishes for discharge 86,000 cubic feet per second from Lake Superior, 225,000 cubic feet from Michigan and Huron, 265,000 cubic feet from Erie through the Niagara, and 300,000 cubic feet per second from Lake Ontario. Its aggregate discharge is double that of the Ohio, nearly half that of the Mississippi, and represents about one-half the rainfall, while in the case of the Ohio and Mississippi the discharge is equal to about one-quarter of the rainfall. The total bulk of water in the system is about 6,000 cubic miles, nearly one-

half of which is in Lake Superior. This amount "would sustain Niagara Falls in its present condition for about 100 years."*

Portions of Lakes Erie and Ontario, the Niagara River, and the upper St. Lawrence itself, lie within the State of New York; and while it is this portion alone which properly concerns us, no adequate discussion of the New York section of the system can be presented without including the entire drainage area. Naturally, the question of the origin and history of this interesting river system has attracted wide attention and has been the subject of much investigation and theorization. As the result, there have been gathered a large number of facts of various kinds, and there have been proposed numerous hypotheses.

It is no small task to weigh these facts and candidly discuss the various hypotheses; but since this has never been done, it seems well to attempt it. Within the limits of this series, it is not possible to do this with completeness, although the attempt is made to so discuss the subject as to consider the salient points. It must be admitted in advance that, in the main, a definite result will not be attained from this discussion; it is too early for final conclusions. But some facts and conclusions will be found to be established, while others may be considered probable. Never having written upon this general subject before, though for several years having had the question in mind, I feel able to approach it without bias, though in discarding as untenable some of the hypotheses that have been proposed, and in arguing against others, I realize that the advocates may not stand ready to accept my conclusions. All I claim for this discussion is that it is based upon a certain familiarity with the region, a careful and extended reading of the more important papers, and a candid consideration of the facts obtained from these two sources.

PREGLACIAL HISTORY.—It is evident that before the glacial period, the country included in this river system, together with other parts of northeastern North America, had for a long time been subjected to denudation. No modern geologist questions this, and the evidence of it may be found on every hand. The result of this exposure to denudation was the transformation of the land into a series of hills and valleys, occupied and drained by rivers. Our *general* land topography has been produced by this long denudation, and no one questions that at least a part of the form and

* Schermerhorn, Amer. Journ. Sci., 1887, CXXXIII, 282.

topography of the valleys of the Great Lakes has resulted from its action.*

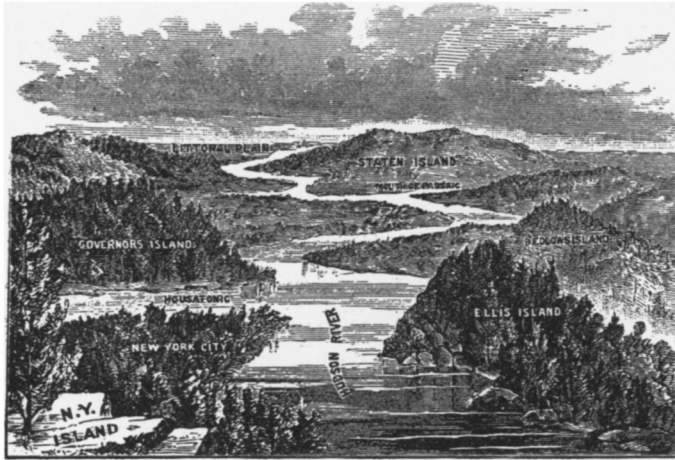


FIG. 2.—NEWBERRY'S IDEAL RESTORATION OF THE NEW YORK REGION IN PREGLACIAL TIMES.

Another fact upon which there is probably no difference of opinion, is that, in the period before the general glaciation, the land stood at a higher level than now and that it stood at such a level for a long time. The exact amount of this elevation is unknown; but off the coast of eastern America the depression since that time has been enough to completely submerge the lower ends of some river valleys, while in the region of the present lower St. Lawrence it was enough to drown the main valley and its tributaries, such as the Saguenay. The elevation certainly amounted to many hundreds of feet, and it lasted long enough for rivers to carve deep and broad valleys of mature form, portions of which are now completely obscured from view by a submergence below the ocean water.

Whether the lakes existed before the glacial period, can not be stated positively upon direct evidence, though without doubt most physiographic geologists will agree that they did not. The reasons for this conclusion are, in the first place, that we know of no cause for their existence immediately before the glacial period. Lakes, even the great ones, are not long-lived, as geological time goes, and had they been formed in periods much earlier than this, they would

* Agassiz (Proc. Amer. Soc. Adv. of Sci., 1849, I, 79; Lake Superior, Boston, 1850, 417-426) points out that the detailed outline of part of the shore of Lake Superior is due to the presence of dikes, indicating that denudation has been influenced by them.

have long since been destroyed by filling. In the second place, and more important than the other point, it may be said that, had they existed, there should have been formed extensive lake deposits, containing lake fossils, some evidence of which should have been discovered in the course of the careful study of the lake shores and the drift-covered country south of them. This negative evidence, and the fact that lake basins must have a definite cause, has weight

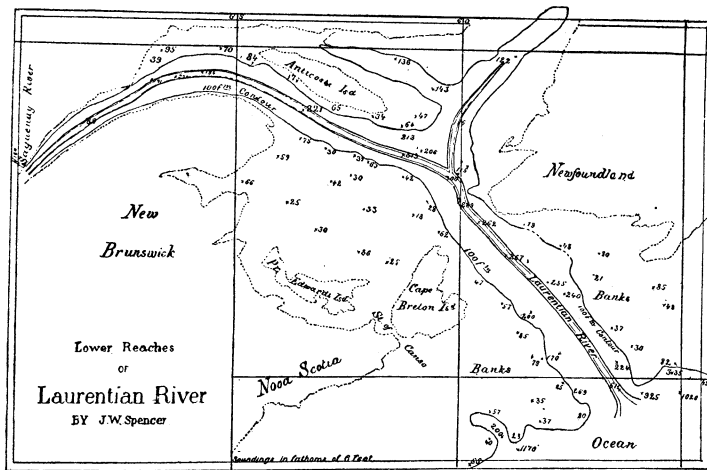


FIG. 3.—SPENCER'S INTERPRETATION OF THE PREGLACIAL COURSE OF THE LOWER ST. LAWRENCE.

of sufficient importance to lead to the conclusion that the Great Lakes probably did not exist in preglacial time.

By what, then, were the present valleys occupied? In considering this, we leave for future discussion the question of the origin of the present *closed* basins and assume the existence of valleys, without raising the question whether they were then as deep as now. Were these valleys occupied by the preglacial St. Lawrence River? This question may be answered positively by the statement that no such river existed along the present line of passage of the St. Lawrence water. Whatever the preglacial drainage may have been, no river that was able to form an upper valley like that of Superior, Huron and Michigan would then change to a Detroit river, or to a Niagara. All would agree that the present course is not *exactly* the preglacial course.

However, when we come to consider how far this preglacial course differed from the present one, we come to a point where diversity of opinion exists. Numerous attempts to reconstruct parts or the whole of the preglacial drainage have been made, and

some investigators have pointed out the existence of buried channels revealed by borings and have shown that they may represent the preglacial courses of some parts of the St. Lawrence system.

For instance, Newberry* notes the existence of buried river valleys, notably the Cuyahoga, which enters the valley of Lake Erie at a depth considerably below the lake surface. This he takes as evidence that the Lake Erie valley was a preglacial valley at a time when the land stood higher. This was the time when the drowned valleys of the coast were formed.

This view is carried a step further in later articles,† where he points out the existence of a buried channel at Detroit 130 feet below the city, and another south of Lake Michigan 230 feet deep. He also shows that Onondaga Lake of New York has beneath it a depth of 414 feet of drift deposit, so that the rock surface here is 50 feet below sea level.‡ The great depth of drift near Syracuse, together with other facts, led Newberry to the conclusion that the preglacial drainage of at least the eastern lakes found outlet through the Mohawk and the Hudson.§ This interpretation is opposed by Carll,|| and by Lesley,** the latter calling attention to the fact that, according to this view, there must be a channel near Little Falls, New York, with at least 1,000 feet of drift-filling. It is doubtful if any one who is familiar with the Mohawk valley would now hold this view of Newberry's, for there seems to be no opportunity for such a river at this place. At Little Falls the valley is crossed by

* Proc. Boston Soc. Nat. Hist., IX, 1862-63, 42-46. See also later articles by Newberry (referred to on p. 111). Also Winchell, Amer. Journ. Sci., 1871, CII, 15-19; Orton, Geol. Survey Ohio, Vol. I, 1873, 425-434, 438-449, 455-462; Geol. Survey Ohio, Vol. VI, 1888, 772-782; Spencer, Proc. Amer. Phil. Soc., XIX, 1880-81, 300-337, and later articles, see p. 112; Foshay, Amer. Journ. Sci., XL, 1890, 397-403; Leverett, Amer. Journ. Sci., XLII, 1891, 200-212; Hershey, Amer. Geol., 1893, XII, 314-323; Mudge, Amer. Geol., 1893, XII, 284-288; Same, 1894, XIV, 301-308; Same, Amer. Journ. Sci., 1895, L, 442-445; Same, Amer. Journ. Sci., 1897, IV, 383-386; Chamberlin and Leverett, Amer. Journ. Sci., 1894, XLVII, 247-283; Upham, Bull. Geol. Soc. Amer., 1896, VII, 327-348; Same, 1897, VIII, 6-13; Pierce, Amer. Geol., 1897, XX, 176-181.

† Newberry, Geol. Survey Ohio, 1869, 24-31; Annals N. Y. Lyceum Nat. Hist., 1870, IX, 213-234; Amer. Nat., 1870, IV, 193-214.

‡ Newberry first said that the Cuyahoga channel was 100 feet below the lake surface; but later (Geol. Survey Ohio, 1873, I, 175) he shows that the depth is as much as 228 feet. Upham, Bull. Geol. Soc. Amer., 1897, VIII, 6-13, finds the depth of the channel to be 470 feet below lake level.

§ Pop. Sci. Mon., 1878, XIII, 641-660; Proc. Amer. Phil. Soc., 1882-83, XX, 91-95.

|| Second Geol. Survey Pennsylvania, 1880, Report III, 369.

** Proc. Amer. Phil. Soc., 1882-83, XX, 95-101.

rock, and on either side of this there is no place for the existence of a valley of this depth and of sufficient width to correspond to the depth. Moreover, Brigham* has recently proved very clearly that the region about Little Falls represents a divide, and that the Mohawk is a complex of two streams, one east-flowing, the other west-flowing.

Spencer has also† attempted to reconstruct the pre-glacial drainage of the Great Lakes and has pointed out the existence of numerous buried valleys, notably one apparently connecting Lakes Erie and Ontario, via Hamilton, in Ontario. He has realized the difficulty of proposing an outlet for Ontario, because neither the Mohawk nor the St. Lawrence courses seem adequate, and there is no other place apparent. This difficulty he meets by assuming that the outlet has been closed by the tilting of the land, so that the old valley, which was approximately along the line of the present St. Lawrence, no longer slopes eastward. As will be seen by the map (Fig. 4),

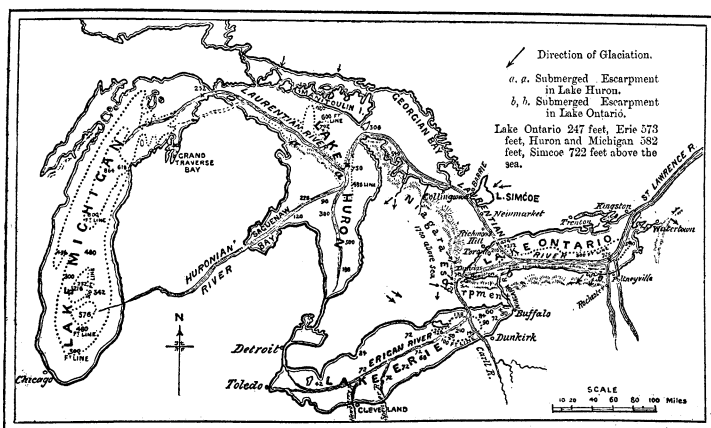


FIG. 4.—SPENCER'S INTERPRETATION OF THE PREGLACIAL COURSE OF THE DRAINAGE OF THE GREAT LAKES REGION.

Spencer locates the sites of these supposed rivers, and gives them names.

* Bull. Geol. Soc. Amer., 1898, IX, 183-210.

† Proc. Amer. Phil. Soc., 1880-81, XIX, 300-337; Second Geol. Survey Pa., Rept. QQQQ, 1881, 357-406; Proc. Amer. Assoc. Adv. Sci., 1881, XXX, 131-146; Same, 1888, XXXVII, 197-199; Bull. Geol. Soc. Amer., 1889, I, 65-70; Quart. Journ. Geol. Soc., 1890, XLVI, 523-533; Amer. Geol., 1891, VII, 86-97; Pop. Sci. Mon., 1896, XLIX, 157-172; Amer. Geol., 1898, XXI, 110-123. A number of Spencer's papers are republished in the appendix of the 11th Ann. Rept. of the Niagara Reservation Commission, 1895. Some of Spencer's other papers (referred to in the continuation of this article in the next number) refer to this view of the preglacial drainage.

Still another view of the former course of the drainage of the Great Lakes region is that much of the water formerly outflowed to the Gulf of Mexico through the Mississippi River.* Our knowledge of the Canadian region is too limited to permit the assumption that none of the drainage found its way northward in preglacial times.

Thus it is seen that, while we know that there were valleys in preglacial times, there is no consensus of opinion as to their course. On the part of some it has been a common assumption that the buried valleys discovered in borings are all preglacial; but by others it has been suggested that some of them are interglacial. For instance, Newberry† says that the preglacial valleys having been enlarged, were later connected by cañons, and again occupied by ice, and finally by drift. Upham‡ explains the narrow and deep cañon-like buried valleys as a result of the uplift which preceded the glacial period.

From this maze of conflicting opinions it is difficult to determine upon the correct explanation. One point seems fairly clear,—that the *preglacial* valleys were not as deep as the present ones. The lake basins are broad, boat-shaped valleys; but there are no equivalent valleys connecting them. Instead, deep cañons are found in a few places, and these are assumed to represent the connecting rivers. Those who advocate this fail to explain why a broad valley abruptly narrows to a cañon, when there is no noticeable variation in rock structure.

Since there are no broad, connecting valleys, it follows that the present depth of the basins has been caused by some change in conditions, and this conclusion will be discussed later. How much these have been deepened is not now apparent; but from all the facts that we have, there are none which would disprove the view that the old valley bottoms might have been as high as the level of the present lake surface. With so much uncertainty, it is evident that it is difficult to trace the preglacial course of the rivers involved in the carving of the valleys.

The buried gorges connecting the basins may be due to immediately preglacial uplift, as suggested by Upham,§ or they may be

* See, for instance, Russell, *Lakes of North America*, Boston, 1897, p. 97; Upham, *Amer. Geol.*, 1896, XVIII, 169-177, and Upham, *Bull. Geol. Soc. Amer.*, 1897, VIII, 6-13.

† *Proc. Amer. Phil. Soc.*, 1882-83, XX, 91-95. See also Hershey, *Amer. Geol.*, 1893, XII, 314-323.

‡ *Bull. Geol. Soc. Amer.*, 1897, VIII, 6-13.

§ *Bull. Geol. Soc. Amer.*, 1897, VIII, 6-13.

interglacial gorges. They are certainly younger in form, and hence in age, than the preglacial valleys with which they are associated; and while they *may* mark the approximate course of the preglacial rivers, they may, on the other hand, represent a course far divergent from the original preglacial one. So it seems that any argument in favor of preglacial courses which is based upon evidence obtained from the drift-filled cañons is not necessarily valid.

My own belief is, that the present Great Lake system is a complex made by the union of portions of several streams as the result of various accidents, particularly the glacial accident. There may be portions of the St. Lawrence, of the Mississippi, and even possibly of the Arctic drainage, united by these accidents to form the present complex.

One of the reasons for proposing this view is that there appears to be no continuous development of the system in any one direction. A river valley naturally broadens from its head to its mouth. The Great Lakes system does not do so, either toward the Mohawk, St. Lawrence or Mississippi. The St. Lawrence itself, it is true, does broaden eastward; but this is not connected with a similar change in that part of the system occupied by the Great Lakes.

Another argument against the belief that this region represents a single preglacial system is the fact that the drainage area is so small. In a number of places the divide is so close to the lake shore that we can see the lake from the divide, and nowhere is it far removed from it. It is true that the system has been robbed of some of its preglacial drainage;* but even restoring this liberally, there still remains a drainage area so small, with tributaries of large size so notably few, that the condition seems an impossible one for a large system. Moreover, in a river system hundreds of miles in length, there should naturally be an increase in the number of large tributaries as one passed down stream; but no such increase is noticed in the case of these lakes. In other words, they do not have the appearance of a part of a *single* large system.

ORIGIN OF THE LAKE BASINS.—Whatever view has been prominently held concerning the preglacial history of this region, it has been uniformly agreed that during or immediately after the glacial

* Carll, Second Geol. Survey Pa. Rept. III, 1880, 330-397; Same, Rept. IIII, 1883, 169-175; Foshay, Amer. Journ. Sci., 1890, XL, 397-403; Chamberlin and Leverett, Amer. Journ. Sci., 1894, XLVII, 247-283; Brigham, Bull. Geol. Soc. Amer., IX, 1888, 183-210; Tarr, Bull. Amer. Geog. Soc., XXX, 1898, 379-382, 389-390, etc.

period, the preglacial valleys have been transformed to basins. It has been shown that in northern Europe and America the zone of abundant lakes lies within the glaciated belt. While we now know that most of these lakes are the result of irregular drift deposits, Ramsay advocated the view that many were due to ice erosion,* and suggested that the Great Lakes themselves were rock basins carved out by ice erosion.

It is to Newberry,† however, that we owe the full development of this idea of ice erosion as applied to the Great Lake basins. He recognizes Lake Superior as a synclinal trough, but believes that the other basins have been cut by some mechanical agent out of formerly continuous and nearly horizontal sheets of sedimentary strata. This mechanical agent he believes must be either ice, or water, or both. He notes that all have been filled by ice, and says,‡ “No other agent than glacial ice, as it seems to me, is capable of excavating broad, deep, boat-shaped basins like those which hold our lakes.” The ice movement is favorable to this explanation.§ Others have followed Newberry in ascribing the lake basins to ice erosion in part at least.||

Carll** believes that there were at first preglacial valleys which were somewhat enlarged by the glaciers, but mostly increased in size by subglacial waters. From his statement, it is not perfectly clear just how he accounts for all the facts by this action, and it is doubtful whether he would hold this view at the present time.

In his discussion of the Red River valley, General Warren ††

* Quart. Journ. Geol. Soc., 1862, XVIII, 185-204; Amer. Journ. Sci., 1863, XXXV, 324-345; Physical Geology and Geography of Great Britain, 1872, 176.

† Proc. Boston Soc. Nat. Hist., 1862-63, IX, 42-46; Geol. Survey Ohio, 1869, 24-31; Ann. New York Lyceum Nat. Hist., 1870, IX, 213-234; Amer. Nat., 1870, IV, 193-214; Geol. Survey Ohio, Vol. I, 1873, 47-49, 174-184; Same, Vol. II, 1874, 21-65, 72-80; Proc. New York Lyceum Nat. Hist., 1874, II, 136-138; Geol. Survey Ohio, III, 1878, 32-51; Proc. Amer. Phil. Soc., 1882-83, XX, 91-95.

‡ Ann. New York Lyceum Nat. Hist., 1870, IX, 232.

§ See Newberry, Proc. Amer. Phil. Soc., 1882-83, XX, 91-95. See also Chamberlin's map of glacial striae, 7th Ann. Rep. U. S. Geol. Survey, 1888, facing p. 155.

|| See, for instance, Logan, Geol. Survey of Canada, 1863, p. 889; Winchell (for Green Bay) Amer. Journ. Sci., II, 1871, 15-19; Russell, Pop. Sci. Mon., 1876, IX, 539-546; Gilbert, Forum, V, 1888, 417-428; Tarr, Bull. Geol. Soc. Amer., 1894, V, 339-356 (see criticism of this by Spencer, Amer. Geol., 1894, XIV, 134-135, and reply by Tarr, Same, 194-195).

** Second Geol. Survey Pa., Rept. III, 1880, 367-376.

†† Ann. Rept. Chief of Engineers, 1868, 307; Amer. Journ. Sci., 1878, XVI, 416-431.

brings forward evidence of tilting of the land; and Spencer,* who has vigorously opposed ice erosion, even to the extent of denying its potency as a partial agency, applies this change of level, which Gilbert had previously proved to have occurred in the Great Lakes region, to the explanation of the basins of the lakes. In his various papers he argues that the tilting of the land has actually closed some of the valleys, notably that of Ontario, transforming them to basins, so that the failure to find an outlet is not proof of ice erosion. According to Spencer, the differential elevation, which was greatest in the north and northeast, formed three lakes—Superior-Huron-Michigan, Erie and Ontario. Spencer affirms that the glacial striæ are not parallel to the lake basins and hence that the ice erosion theory is not tenable.

While others besides Spencer have argued against the glacial erosion theory,† perhaps the strongest argument against it is that by Claypole,‡ who holds that glaciers are not powerful enough to perform the work, and that the drift supposed to have been excavated from the basins does not exist to the south of them. Davis§ says that the evidence of glacial erosion is very meagre, hardly more than proof that the valleys were occupied by ice (p. 341 in §). The rocks are nearly horizontal, and the lakes lie mostly in the softer rocks. Davis inclines toward drift obstruction of the river valleys as the chief cause for the basins (p. 362 in §). Upham || believes the chief cause of the basins to be warping of the crust before, during and after the ice age. No doubt most of these writers, while advocating one cause as the prime one, would agree to the hypothesis that several causes have co-operated, as is stated

* Proc. Amer. Phil. Soc., 1880-81, XIX, 300-317; Sec. Geol. Survey Pa., Rept. QQQQ, 1881, 357-406; Proc. Amer. Assoc. Adv. Sci., 1881, XXX, 131-46; Geol. Mag. 1887, IV, 167-173; Amer. Nat., 1887, XXI, 168-171; Proc. Amer. Assoc. Adv. Sci., 1888, XXXVII, 197-199; Bull. Geol. Soc. Amer., I, 1889, 65-70; Quart. Journ. Geol. Soc., 1890, XLVI, 523-533; Amer. Journ. Sci., 1891, XLI, 12-21; Amer. Geol., 1891, VII, 86-97; Proc. Amer. Assoc. Adv. Sci., 1894, XLIII, 237-43; Amer. Geol., 1894, XIV, 298-301; Pop. Sci. Mon., 1896, XLIX, 157-172; Amer. Geol., XXI, 1898, 110-123; 11th Rept. Niagara Comm., 1895, Appendix (reprint of several papers). For a more complete list of Spencer's papers, see second part of this paper in next number of the Bulletin.

† See, for instance, Lesley, Second Geol. Survey Pa. Rept. QQQQ, 1881, 399-401; Proc. Amer. Phil. Soc., 1882-83; XX, 95-101; Bonney, Nature, XLIII, 1891, 203-4.

‡ Proc. Amer. Assoc. Adv. Sci., 1882, XXX, 147-159.

§ Proc. Boston Soc. Nat. Hist., 1883, XXI, 315-381.

|| Amer. Geol., 1896, XVIII, 169-177.

by Davis,* and by Russell,† who, though first advocating ice erosion, now believes them to be due to land movement and other causes.

Perhaps the broadest statement of origin of the Great Lakes is that by Chamberlin,‡ who ascribes the Great Lakes basins to the joint action of "preglacial erosion, glacial corrasion, glacial accumulation blocking up outlets, depression due to ice occupancy and general crust movements, together with possible unascertained agencies." This is certainly broad enough. Taylor§ believes in four causes—stream action, tilting of the land, obstruction by drift and deepening by ice action. He believes the basins to be mainly due to old river valleys which have been tilted and choked by deposits, but thinks that the ice sheet had little or no tendency to deepen.

As in the preceding section, it is difficult to select from these opposing views one which correctly explains the phenomena. That the basins are not due solely, or even primarily, to drift obstruction seems evident. It is inconceivable that there are buried and completely obliterated broad preglacial valleys; and, while we may agree that there *are deeply drift-filled valleys* between the lakes, it seems certain, from all the evidence, that these are *narrow* valleys formed in quite a different way from the broad, boat-shaped basins. The failure to find outlet channels, as, for instance, for the Ontario basin, may possibly be due to incomplete study; but it has been commonly assumed to prove that this basin is rock-rimmed, and all the evidence that we have tends to confirm this view. There could hardly be a valley over 700 feet deep and broad enough to form the continuation of the preglacial Ontario valley, which is so completely obscured by drift that not the least trace of it has been found on the surface.

I feel that we may safely say that the upper lake valleys are disconnected, excepting possibly by narrow cañons. The *possibility* of such connecting cañons as deep as the lake basins themselves cannot be denied, but the probabilities are very much against their existence. So we are to explain, if not a rock basin, at least a rock basin in all parts excepting where these undiscovered buried channels exist. In other words, we must account for the deep boat-shaped basins, the problem which Newberry attempted to solve.

Excepting Superior, which is stated to be in a synclinal valley,

* Proc. Boston Soc. Nat. Hist., 1883, XXI, 341, 362.

† Lakes of North America, 1895; Bull. Amer. Geog. Soc., 1898, XXX, 226-254.

‡ Proc. Amer. Assoc. Adv. Sci., 1883, XXXII, 212.

§ Dryer's Studies in Indiana Geology, Terre Haute, 1897, 92-93.

these basins are not due to structural causes. They lie in a region of nearly horizontal strata, so uniform in structure that the alternate expansion and contraction of the basins seems impossible on the assumption of mere river erosion. It is, however, proposed as a theory that a broad river valley, the preglacial St. Lawrence, has been warped so as to form these basins. That there has been warping, and that this has had marked influence on the form and depth of the lakes, must be admitted, as must also be the certainty that drift deposit in pre-existing valleys has tended to the same result. But to ascribe to such warping the predominant influence seems an extravagant use of the facts. It is a curious fact, if this explanation be true, that this particular region should have been selected for such warping, and have produced five great basins, when other valleys not far different, nor greatly removed from these, as, for instance, the Red River Valley of the North, where warping has also occurred, have not been transformed to basins. This, of course, is not an unanswerable argument against warping, but it may be pointed to as opposing evidence.

The warping has been complex, if it is the prime cause for the basins; and it has been considerable if it is the cause for the depth of 700 or 800 feet noticed in Ontario and Michigan; for, as has been pointed out before, we have to account for a *deep, broad* valley. Nearly the entire depth of each of these lakes must be accounted for by some other cause than river erosion, for it has been shown that the only possible valleys markedly below the lake levels are gorges, and hence that the only possible deep preglacial valleys along the sites of the present lakes, and markedly deeper than the present water surface, must have been gorges and not broad basins. So, in order to account for the basins by warping, we must assume warping to nearly the full extent of the present lake depth. Of such marked change in level there is no evidence either in the strata, or in the tilted beaches; and it is doubtful if such warping has actually taken place.

In various parts of New York and the neighboring States gorges are found, which some have ascribed to interglacial river action, others to the immediately preglacial uplift which rejuvenated the region. It is a significant fact that, although these deep valleys have been discovered along the lake shore, and buried gorges appear to connect some of the Great Lakes, there is no sign of their existence on the lake bottom, as we might expect if the lake basins were due to warping. While this is not necessarily proof of their absence along the lake bed, it is suggestive.

So far as I am able to interpret the facts at present known, while Superior is perhaps located in a structural valley, and Erie very probably represents a broad, shallow valley, somewhat obscured by glacial deposit and transformed to a lake largely by the northward tilting of the land, and while both drift filling and tilting can be admitted as partial causes for the other lakes, I am unable to accept the warped basin origin as the primary cause for the lakes. This leaves as the sole remaining explanation that of ice erosion. By this theory much, if not most, of the depth of the basins is ascribed to glacial erosion, operating to enlarge pre-existing valleys to boat-shaped basins.

It must be admitted that the process of elimination of other theories has probably not been complete enough to satisfy their advocates; and, perhaps, in this brief statement the argument has not been as clearly stated as it might have been. Enough has been said, however, to show that there are grave difficulties. Let us see if the ice erosion theory has equal objections. The argument *against* this theory has been very weak in the main. Contrary to opposing statements, the striæ *do* run in favorable directions, in the case of all the lakes excepting possibly Erie, which is least likely to be a rock basin of ice erosion origin. Professor Claypole's argument that there is not enough drift beyond the lakes to account for the basins through ice erosion would probably not now be repeated. As for Ontario, the lake concerning which I would especially speak, there is drift enough between its southern border and the Pennsylvania moraine, and directly in line with it, to fill it many times. It must also be remembered that a vast amount of the ice load of rock fragments went down toward and even to the ocean.

Professor Davis' statement; that the evidence in favor of the ice erosion theory is hardly more than proof of occupancy of the basins, scarcely does justice to Newberry's argument. Newberry's point that we have here several separated, boat-shaped basins, although never fully elaborated by him, is a point which must be considered as strong evidence for the theory. Spencer's chief argument against the ice erosion explanation, namely that ice cannot do this work, is based upon a personal estimate of the ability of ice, which he gained partly from theory and partly from observation on the *margin* of small Norwegian glaciers. One can scarcely study the existing Greenland ice cap and the American glacier deposits and still hold such a conception of the weakness of ice action. How Dr. Spencer reconciles his conception with the fact that the ice removed not

only the residual soil and partly decayed rock over large areas, but also considerable fresh rock, is difficult to understand.

I have often wondered whether those who object to ice erosion because of the immense work required, are not sometimes confused by the exaggerated vertical, which is necessary in cross section. I have heard people say that they did not believe glaciers were able to come down into a valley and dig a hole there. If one will draw a cross-section of the Ontario or the Lake Cayuga "hole," or will ascend to a hill overlooking such a lake as Cayuga, and see what a mere scratch the basin is compared with the valley itself, the difficulty of the ice erosion does not appear so great, as I well know from repeated experiments with students who have argued against the theory that Lake Cayuga is a rock basin.

In the long continued passage of the ice through a valley, a very little extra work done locally, where the rock is soft, or the ice deep, or its current more rapid than usual, would readily excavate a basin. Are there any reasons for believing that there might have been slightly more work done in the valley where Ontario now stands? The answer to this seems to be *yes*. In the first place there is the difficulty of otherwise explaining it; and, in the second place, there is the fact that the Great Lakes are grouped in a place where the ice from the Labrador region found free passage out over the south-sloping plains, which at that time were probably more freely sloping.

Coming down into these broad, preglacial valleys, which had possibly been deepened by cañon cutting in their bottoms, as the result of the elevation, the glacier passed through them; and the very fact that they were valleys gave to the ice greater power to excavate, as one may see so well illustrated in the rapidly moving valley tongues from the Greenland ice cap. The rigidity of the ice would prevent this excavation from being uniform, as it would be in the case of running water; and, as a result of this irregularity of work, rock basins would necessarily result. In the case of Ontario there is an added cause for deepening at the exact place where we find the valley. The Adirondack mountain mass obstructed the southward flow of the ice, deflecting some down the Champlain valley, but much more to the westward, so that the Ontario region was occupied by ice, coming not merely from the north, but also from the northeast. This must have meant more rapid movement and hence more rapid work at that place.

While I would not say that it is absolutely proved, I do hold that the ice erosion theory is the one to which the least serious objec-

tions can be offered. It seems a reasonable explanation for all the lakes, excepting Erie and possibly Superior, and has stood best the test of investigation; so well, in fact, that I feel warranted in putting it forth as the most probable of all the various theories, though with the distinct understanding that the effects of drift filling and warping are recognized as added causes for the present area and depth of all the lakes, and probably as the chief cause for Erie.